BSR/ASHRAE Standard 55-1992R

**This revision will be submitted to the American National Standards Institute Board of Standards Review (BSR) for approval.**

# ASHRAE®
# STANDARD

**Proposed Revision to an American National Standard**

# Thermal Environmental Conditions for Human Occupancy

## FIRST PUBLIC REVIEW DRAFT

**February 2001**

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This draft has been recommended for public review by the responsible project committee. Public review of this proposed revision has been authorized by a subcommittee of the Standards Committee. Until final approval by the ASHRAE Board of Directors, this draft revision is subject to modification and Standard (designation and year to be filled in) remains in effect. Instructions and a form for commenting are provided with this draft. Although reproduction of drafts during the public review period is encouraged to promote additional comment, permission must be obtained to reproduce all or any part of this document from the ASHRAE Manager of Standards, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. Phone: 404-636-8400, Ext. 502. Fax: 404-321-5478. E-mail: jheldenb@ashrae.org.

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# Thermal Environmental Conditions for Human Occupancy

## Foreword - Introduction

Standard 55-2000R, "Thermal Environmental Conditions for Human Occupancy," is a revision of Standard 55-1992. The standard specifies conditions in which a specified fraction of the occupants will find the environment thermally acceptable. The revision is a consensus standard that has undergone public and ASHRAE review; it incorporates the relevant research and experience gained since the 1992 revision. Principle changes include the addition of the PMV/PPD calculation methods, addition of different classes of space with respect to thermal comfort, and the addition of the concept of adaptation based on ASHRAE sponsored research The standard is intended for use in design, commissioning, operation and testing of buildings and other occupied spaces and their HVAC systems, and for the evaluation of thermal environments. Because it is not possible to prescribe the metabolic rate of occupants, and because of variations in occupant clothing levels, operating set points for buildings cannot be practically mandated by this standard.

The designer may choose in agreement with the builder the thermal comfort class. The selected design criteria will influence the HVAC-system design and may also influence the building design. This standard may also be used for evaluation of existing thermal environments in buildings, during experimental conditions and for development and testing of products.

This standard is in close agreement with ISO Standards 7726 and 7730.

# Table of Contents

# 1. Purpose

To specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space.

# 2. Scope

**2.1** The environmental factors addressed are temperature, thermal radiation, humidity, and air speed; the personal factors are those of activity and clothing.

**2.2** It is intended that all of the criteria in this standard be applied together, since comfort in the indoor environment is complex and responds to the interaction of all of the factors that are addressed.

**2.3** This standard specifies thermal environmental conditions acceptable for healthy adults at atmospheric pressure equivalent to altitudes up to 3000 m (10,000 ft) in indoor spaces designed for human occupancy for periods not less than 15 minutes.

**2.4** This standard does not address such non-thermal environmental factors as air quality, acoustics, and illumination; or other physical, chemical or biological space contaminants that may affect comfort or health.

# 3. Definitions

**adaptive model:** a model that relates indoor design temperatures or acceptable temperature ranges to outdoor meteorological or climatalogical parameters.

**air speed:** the rate of air movement at a point, without regard to direction. This term is preferred to air velocity, which assumes a known direction.

**clo**: a unit used to express the thermal insulation provided by garments and clothing ensembles, where 1 clo = 0.155 $m^2$ °C/W (0.88 $ft^2$·h·°F/Btu).

**comfort, thermal**: that condition of mind which expresses satisfaction with the thermal environment; it requires subjective evaluation.

**draft**: the unwanted local cooling of the body caused by air movement.

**environment, thermal**: the characteristics of the environment which affect a person's heat loss.

**environment, acceptable thermal**: an environment which a substantial majority of the occupants would find thermally acceptable.

**garment**: a single piece of clothing.

**humidity ratio:** the ratio of the mass of water vapor to the mass of dry air in a given volume.

**humidity, relative (rh)**: the ratio of the partial pressure (or density) of the water vapor in the air to the saturation pressure (or density) of water vapor at the same temperature.

**insulation, clothing/ensemble** ($I_{cl}$): the resistance to sensible heat transfer provided by a clothing ensemble. Expressed in clo-units

**insulation, garment** ($I_{clu}$): the increased resistance to sensible heat transfer obtained from adding an individual garment over the nude body. Expressed in clo-units

**met:** a unit used to describe the energy generated inside the body due to metabolic activity. It is defined as 58.2 W/$m^2$ (18.4 Btu/h×$ft^2$) which is equal to the energy produced per unit surface area of a average person, seated at rest. The surface area of an average person is 1.8 $m^2$ (19 $ft^2$).

**metabolic rate (M):** rate of energy production of the body by metabolism, which varies with activity. Expressed in met units in this standard.

**naturally conditioned spaces:** those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of the windows.

**neutrality, thermal:** the indoor thermal index value corresponding with a mean vote of neutral on the thermal sensation scale.

**Predicted Mean Vote (PMV):** an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale.

**Predicted Percentage of Dissatisfied (PPD):** an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV.

**radiant asymmetry:** the difference between the plane radiant temperature of the two opposite sides of a small plane element.

**response time (90%):** the time for a measuring sensor to reach 90% of the final value after a step change. For a measuring system that includes only one exponential time-constant function, the 90% response time equals 2.3 times the “time constant”.

**sensation, thermal**: a conscious feeling commonly graded into the categories, cold, cool, slightly cool, neutral, slightly warm, warm, and hot; it requires subjective evaluation.

**step change:** an incremental change in a variable, either by design or the result of an interval between measurement, typically, an incremental change in a control set-point.

**temperature, air ($t_a$)**: the temperature of the air surrounding the occupant.

**temperature, dew point ($t_{dp}$):** the temperature at which air becomes saturated (100% relative humidity) with water vapor ($P_{sdp} = P_a$) when cooled at constant pressure.

**temperature, mean monthly outdoor air ($t_{a(out)}$):** when used as input variable in Figure ~~6.3.1~~ 5.3.1 for the adaptive model this is based on the arithmetic average of the mean daily minimum and mean daily maximum outdoor (dry bulb) temperatures for the month in question.

**temperature, mean radiant ($t_r$):** the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space.

**temperature, operative ($t_o$):** the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment.

**temperature, plane radiant ($t_{pr}$):** the uniform temperature of an enclosure in which the incident radiant flux on one side of a small plane element is the same as in the existing environment.

**time constant**: the time for a measuring sensor to reach 63% of the final value after a step change.

**turbulence intensity (Tu)**: the ratio of the standard deviation of the air speed ($SD_v$) to the mean air speed (v). Turbulence intensity may also be expressed in percent [i.e., Tu = ($SD_v$/ $v_a$ ) x 100].

**water vapor pressure ($p_a$)** :the pressure which the water vapour would exert if it alone occupied the volume occupied by the humid air at the same temperature.

**velocity, mean ($v_a$ ):** an average of the instantaneous air velocity over an interval of time.

**velocity, standard deviation ( $SD_v$ ):** a measure of the scatter of the instantaneous air velocity around the mean air velocity in a frequency distribution and it is defined as the square root of the arithmetic average of a set of square values of the difference between the instantaneous air velocity and the mean air velocity. The standard deviation is based on individual values of airspeed that represent an average over no more than two seconds each..

**zone, occupied:** the region normally occupied by people within a space, generally considered to be between the floor and 1.8 m (6 ft) above the floor and more than 1.0 m (3.3 ft) from outside

walls/windows or fixed heating, ventilating or air conditioning equipment and 0.3 m (1 ft) from internal walls.

# 4. General Requirements

Use of this standard is specific to the space being considered and the occupants of that space. Any application of this standard must specify the space to which it applies and the locations within that space to which it applies if not the entire space. Any application of this standard must identify to which occupants, with a residency of more than 15 minutes in the space, it applies.

The activity and clothing of the occupants must be considered in applying this standard. When there are substantial differences in physical activity and/or clothing for occupants of a space, these differences must be considered.

It may not be possible to simultaneously meet the requirements of this standard for all occupants of a space due to differences in activity and/or clothing. If the criteria are not met for some occupants, then those occupants must be identified.

The thermal environmental conditions required for comfort are determined according to section 5.2 or section 5.3 of this standard. Any application of this standard must clearly state which of these sections is used. Additionally, all requirements of the applicable section, 5.2 or 5.3, must be met. If section 5.2 is used, the class of environment, A, B, or C, must be specified. If section 5.3 is used, the satisfaction level, 80% or 90%, must be specified.

# 5.0 Conditions Which Provide Thermal Comfort

## 5.1 Introduction

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment. There are large variations, both physiologically and psychologically, from person to person, which makes it difficult to satisfy everybody in a space. The environmental conditions required for comfort are not the same for everyone. However, extensive laboratory and field data have been collected which provide the necessary statistical data to define conditions which a specified percentage of occupants will find thermally comfortable. Section 5 of this standard is used to determine the thermal environmental conditions in a space

which are necessary to achieve acceptance by a specified percentage of occupants of that space.
There are six primary factors that must be addressed when defining conditions for thermal comfort. A number of other, secondary factors affect comfort in some circumstances. The six primary factors are listed below. Complete descriptions of these factors are presented in Section 5.4 and Appendixes A and B.

1) Metabolic rate.
2) Clothing insulation.
3) Air temperature.
4) Radiant temperature
5) Air speed.
6) Humidity .

All six of these factors may vary with time. However, this standard only addresses thermal comfort in steady state. People who have prior exposure to different environmental conditions and/or activity levels may not find the conditions allowed in this standard comfortable upon entry to the space. The effect of prior exposure or activity may affect comfort perceptions for approximately one hour.

Variables 2-6 may be non-uniform over an occupant's body and this non-uniformity may be an important consideration in determining thermal comfort. Non-uniformity is addressed in Section 5.2.4

The vast majority of the available thermal comfort data pertain to sedentary or near sedentary physical activity levels typical of office work. This standard is intended primarily for these conditions. However, this standard may also be used to determine appropriate environmental conditions for moderately elevated activity. It does not apply to sleeping or bed rest. The body of available data does not contain significant information regarding the comfort requirements of children,the disabled or the infirm, but the information in this standard can probably be applied to classroom situations.

Section 5.2 contains the methodology that should be used for most applications. However, the conditions required for thermal comfort in spaces that are naturally conditioned are not necessarily the same as those conditions required for other indoor spaces. Section 5.3 specifies criteria required for a space to be considered naturally conditioned. The methods of Section 5.3 may, as an option, be applied to spaces that meet these criteria. The methods of Section 5.3 may not be applied to other spaces.

Section 5.4 describes in some detail variables that must be clearly understood in order to effectively use the methods of Section 5.

## 5.2 Method for Determining Acceptable Thermal Conditions in Occupied Spaces

When Section 5.2 is used to determine the requirements for thermal comfort, the requirements of all subsections, 5.2.1, 5.2.2, 5.2.3, 5.2.4, and 5.2.5 must be met.

Three different classes of environments with respect to thermal comfort are used in Section 5.2 of this standard: Class A, Class B, and Class C. The user of this standard must specify the class of thermal comfort. Class B is for typical applications and should be used when other information is not available. Class A is used when it is desired to adhere to higher than typical comfort standards and Class C is used when it is desired to relax the typical comfort standards.

### 5.2.1 Operative Temperature

For given values of humidity, air speed, metabolic rate, and clothing insulation, a comfort zone may be determined. The comfort zone is defined in terms of a range of operative temperatures that provides acceptable comfort or in terms of the combinations of air temperature and mean radiant temperature that provide acceptable comfort.

Section 5.2.1 describes methods that may be used to determine temperature limits for the comfort zone. Section 5.2.1.1 uses a simplified graphical method for determining the comfort zone which may be used for many typical applications. Section 5.2.1.2 uses a computer program based on a heat balance model to determine the comfort zone for a wider range of applications. For a given set of conditions, the results from the two methods are consistent and either method may be used as long as the criteria outlined in the respective section are met. See Appendix C and The ASHRAE Handbook of Fundamentals Chapter 8 for procedures to calculate operative temperature.

#### 5.2.1.1 Graphical method for typical indoor environments

The method in Section 5.2.1.1 may be applied to spaces where the occupants have activity levels which result in metabolic rates between 1.0 met and 1.3 met and where clothing is worn which provides between 0.5 clo and 1.0 clo of thermal insulation. See

Appendix A for estimation of metabolic rates and Appendix B for estimation of clothing insulation.  Most office spaces fall within these limitations.

The requirements in this section correspond to Class B thermal environments, defined in Table 5.2.1.2-1.  The range of operative temperatures presented in Figure 5.1.1.1-1 are for 80% occupant acceptability. This is based on a 10% dissatisfaction criteria for general (whole body) thermal comfort based on the PMV-PPD index, plus an additional average 10% dissatisfaction which may occur from local thermal discomfort.

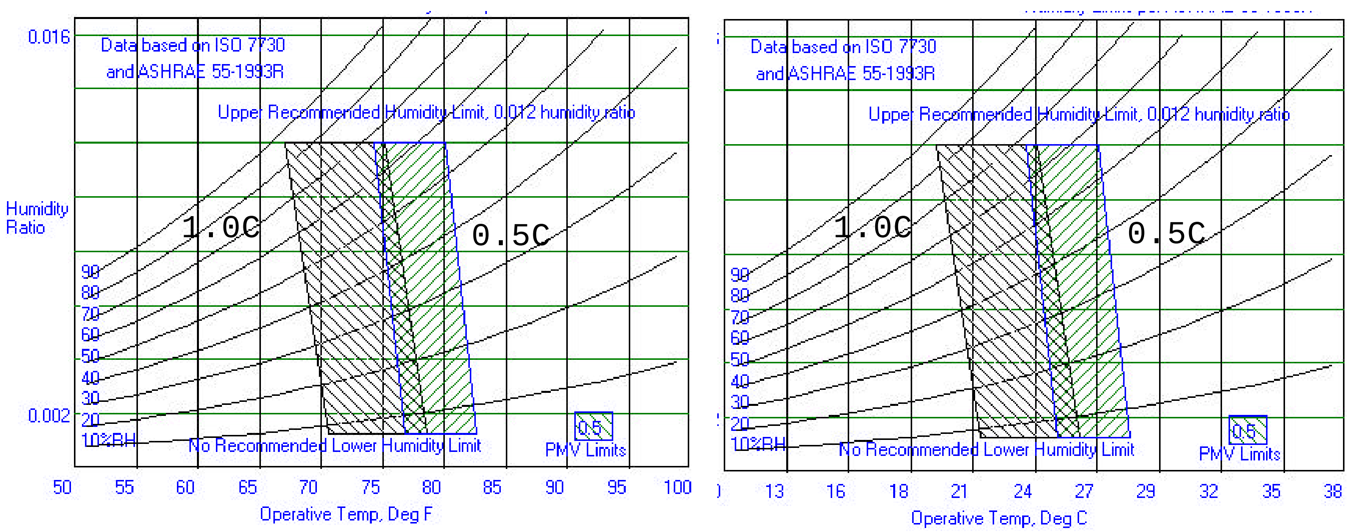



*Figure 5.2.1.1-1.  Acceptable range of operative temperature and humidity for spaces that meet the criteria specified in Section 5.2.1.1.*

Figure 5.2.1.1-1 specifies the comfort zone for environments which meet the above criteria and where the air speeds are not greater than 0.20 m/s (40 ft/min).. Two zones are shown, one for 0.5 clo of clothing insulation and one for 1.0 clo of insulation.  These insulation levels are typical of clothing worn when the outdoor environment is warm and cool respectively. The operative temperature range allowed for intermediate values of clothing insulation may be determined by linear interpolation between the limits for 0.5 clo and 1.0 clo using the following relationships.

$$T_{min,\ Icl} = [(I_{cl} - 0.5\ clo)\ T_{min,\ 1.0\ clo} + (1.0\ clo - I_{cl})\ T_{min,\ 0.5clo}]\ /\ 0.5\ clo$$

$$T_{max,\ Icl} = [(I_{cl} - 0.5\ clo)\ T_{max,\ 1.0\ clo} + (1.0\ clo - I_{cl})\ T_{max,\ 0.5clo}]\ /\ 0.5\ clo$$

where

$T_{max, Icl}$ is the upper operative temperature limit for clothing insulation $I_{cl}$,

$T_{min, Icl}$ is the lower operative temperature limit for clothing insulation $I_{cl}$, and

$I_{cl}$, is the thermal insulation of the clothing in question (clo).

Air speeds greater than 0.20 m/s (40 ft/min) may be used to increase the upper operative temperature limit for the comfort zone in certain circumstances. Section 5.2.3 describes these adjustments and specifies the criteria required for such adjustments.

### 5.2.1.2 Computer model method for general indoor application

The method in Section 5.2.1.2 may be applied to spaces where the occupants have activity levels which result in average metabolic rates between 1.0 met and 2.0 met and where clothing is worn which provides not more than 1.5 clo of thermal insulation. See Appendix A for estimation of metabolic rates and Appendix B for estimation of clothing insulation.

The ASHRAE thermal comfort scale, which was developed for use in quantifying people's assessment of the thermal environment, is defined as follows.

+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

The Predicted Mean Vote (PMV) model uses heat balance principles to relate the six key factors for thermal comfort listed in section 5.1 to the average response of people on the above scale (the PMV). The Predicted Percentage of people Dissatisfied (PPD) with the thermal conditions in an environment is related to the PMV. Figure 5.2.1.2-1 shows this relationship using the criterion that those individuals voting -3, -2, +2 or +3 on the above scale are dissatisfied.

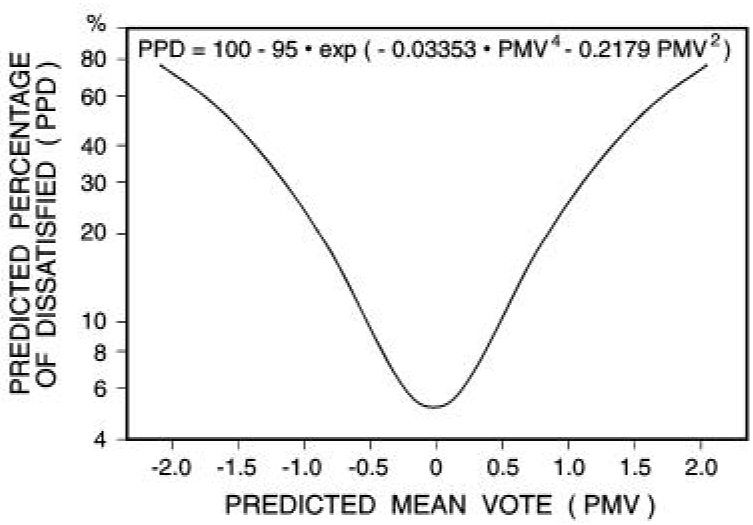



*Figure 5.2.1.2-1. Predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (PMV).*

Table 5.2.1.2-1 defines three classes of thermal comfort based on the PPD allowed. The class of comfort must be specified by the user. The acceptable PMV range corresponding to a given class is determined from this table.

*Table 5.2.1.2-1: Three classes of acceptable thermal environment for general comfort.*

| Comfort Class | PPD | PMV Range |
|---|---|---|
| A | < 6 | -0.2 < PMV < + 0.2 |
| B | < 10 | -0.5 < PMV < + 0.5 |
| C | < 15 | 0.7 < PMV < + 0.7 |

The comfort zone is defined by the combinations of air temperature and mean radiant temperature for which the PMV is within the limits specified in Table 5.2.1.2-1. The PMV model is run with the air temperature and mean radiant temperature in question along with the applicable metabolic rate, clothing insulation, air speed, and humidity. If the resulting PMV value generated by the model is within the range allowed in Table 5.2.1.2-1, the conditions are within the comfort zone.

Use of the PMV model in this standard is limited to air speeds not greater than 0.20 m/s (40 fpm). Air speeds greater than 0.20 m/s (40 ft/min) may be used to increase the upper temperature limits of the comfort zone in certain circumstances. Section 5.2.3 describes these adjustments and specifies the criteria required for such adjustments. The adjustments in Section 5.2.3 are with respect to the upper limit of the comfort zone determined with the PMV model using an air speed of 0.20 m/s (40 fpm).

There are several computer codes available that predict PMV-PPD. The computer code in Appendix D is to be used with this standard. If any other version is used, it is the user's responsibility to verify and document that the version used yields the same results as the code in Appendix D for the conditions for which it is applied.

## 5.2.2 Humidity limits

The maximum moisture content of the air for which this standard applies is a water vapor pressure of 1.910 kPa (0.277 psi) which corresponds to a dew point temperature of 16.8$^{o}$C (62.2$^{o}$F). It also corresponds to a humidity ratio of 0.012 at standard pressure.

Guidance: This specific upper humidity limit may result in condensation on building surfaces. While this concern is beyond the scope of this standard, moisture on surfaces can lead to biological contamination and damage to building components. ASHRAE Standard 62 provides further guidance on humidity limits in buildings.

There are no established lower humidity limits for thermal comfort; and consequently, this standard does not specify a minimum humidity level. However, non-thermal comfort factors such as skin drying, irritation of mucus membranes, dryness of the eyes, and static electricity generation may place limits on the acceptability of very low humidity environments.

### 5.2.3 Elevated air speed

Precise relationships between increased air speed and improved comfort have not been established. However, this standard allows elevated air speed to be used to increase the maximum temperature for acceptable comfort if the affected occupants are able to control the air speed. The amount that the temperature may be increased is shown in Figure 5.2.3-1. The combinations of air speed and temperature defined by the lines in this figure result in the same heat loss from the skin. The reference point for theses curves is the upper temperature limit of the comfort zone and 0.20 m/s (40 fpm) of air speed. This figure applies to a lightly clothed person with clothing insulation between 0.5 clo and 0.7 clo engaged in near sedentary physical activity with metabolic rates between 1.0 met and 1.3 met.

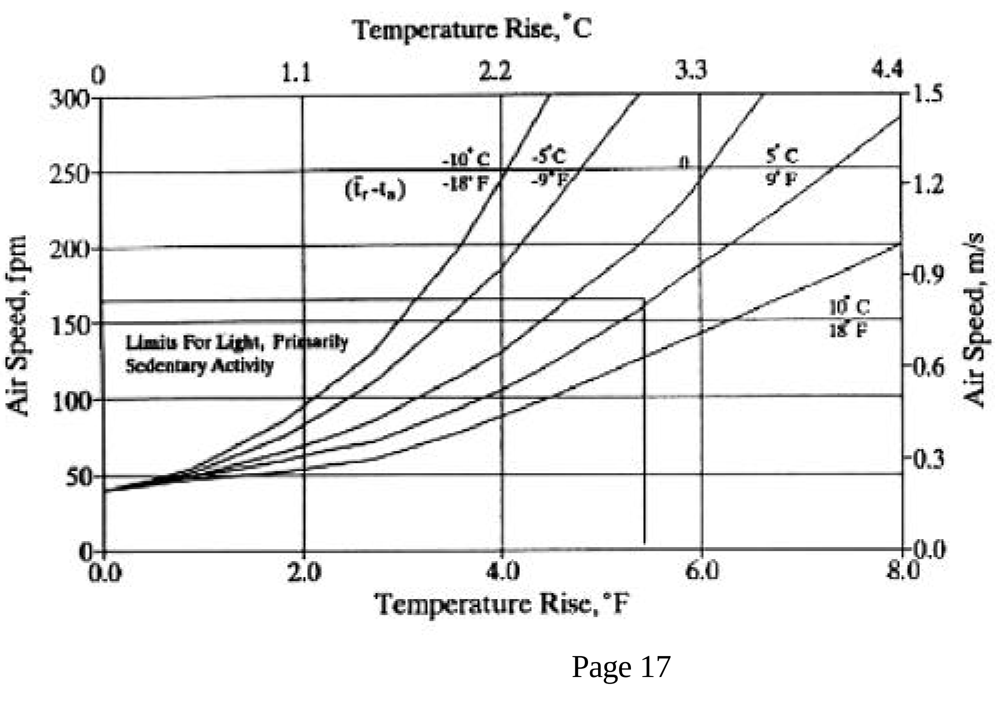


*Figure* 5.2.3-1*. Air speed required to offset increased temperature.*

The indicated increase in temperature pertains to both the mean radiant temperature and the air temperature.  That is, both temperatures increase by the same amount with respect to the starting point.  When the mean radiant temperature is low and the air temperature is high, elevated air speed is less effective at increasing heat loss.  Conversely, elevated air speed is more effective at increasing heat loss when the mean radiant temperature is high and the air temperature is low.  Thus, the curve in Figure 5.2.3-1 that corresponds to the relative difference between air temperature and mean radiant temperature must be used.  It is acceptable to interpolate between curves for intermediate differences.

Elevated air speed may be used to offset an increase in the air temperature and the mean radiant temperature by not more than 3.0° C (5.4F) above the values for the comfort zone without elevated air speed.  The required air speed may not be higher than 0.8 m/s (160 fpm). Large individual differences exist between people in regard the preferred air speed. Therefore the  elevated air speed must be under the direct control of the affected occupants and adjustable in steps no greater than 0.15 m/s (30 fpm). The benefits that can be gained by increasing air speed depend on clothing and activity. Due to increases in skin wettedness, the effect of increased speed is greater with elevated activity than with sedentary activity. Due to increased amounts of exposed skin, the effect of  increased air speed is greater with lighter clothing.  Thus Figure 5.2.3-1 is conservative for activity levels above 1.3 met and/or for clothing insulation less than 0.5 clo and may be applied in these circumstances.

Due to increased body coverage, the effect of increased air speed is less with higher levels of clothing insulation.  Thus, Figure 5.2.3-1 will underestimate the required air speed for clothing insulation greater than 0.7 clo and should not be applied in these circumstances.

### 5.2.4 Local thermal discomfort

The local thermal discomfort caused by a vertical air temperature difference between the feet and the head, by an asymmetric radiant field, by a local convection cooling (draft), or by contact with a hot or cold floor must be considered in determining conditions for acceptable thermal comfort. Requirements for these factors are specified in this section.

The requirements specified in this section apply to a lightly clothed person with clothing insulation between 0.5 clo and 0.7 clo engaged in near sedentary physical activity with metabolic rates between 1.0 met and 1.3 met. With higher metabolic rates and/or with more clothing insulation, people are less thermally sensitive and consequently the risk of local discomfort is lower. Thus, the requirements of this section may also be used for metabolic rates greater than 1.3 met and with clothing insulation greater than 0.7 clo and will be conservative. People are more sensitive to local discomfort when the whole body is cooler than neutral and less sensitive to local discomfort when the whole body is warmer than neutral. The requirements of this section are based on environmental temperatures near the center of the comfort zone. These requirements apply to the entire comfort zone, but may be conservative for conditions near the upper temperature limits of the comfort zone and may underestimate acceptability at the lower temperature limits of the comfort zone.

Table 5.2.4-1 specifies the expected Predicted Percentage Dissatisfied (PPD) associated with each class of thermal environment for each source of local thermal discomfort. The user of this standard must specify the class. The criteria for all sources of local thermal discomfort must be met simultaneously at the levels specified for a class for an environment to meet the requirements for that class.

*TABLE 5.2.4-1. Percentage of dissatisfied due to local discomfort from various sources for different classes of thermal environment.*

| Class | PPD due to draft | PPD due to vertical air temperature difference | PPD due to warm or cool floors, or warmed or cooled ceilings | PPD due to radiant asymmetry |
|---|---|---|---|---|
| | | | | |

| | | | | |
|---|---|---|---|---|
| A | < 10 | < 3 | < 10 | < 5 |
| B | < 20 | < 5 | < 10 | < 5 |
| C | < 20 | < 10 | < 15 | < 10 |

### 5.2.4.1 Radiant temperature asymmetry

The thermal radiation field about the body may be non-uniform due to hot and cold surfaces and direct sunlight. This asymmetry may cause local discomfort and reduce the thermal acceptability of the space. In general, people are more sensitive to asymmetric radiation caused by a warm ceiling than that caused by hot and cold vertical surfaces. Figure 5.2.4.1-1 gives the percentage of dissatisfied occupants as a function of the radiant temperature asymmetry caused by a warm ceiling, a cold wall, a cool ceiling, or a warm wall.

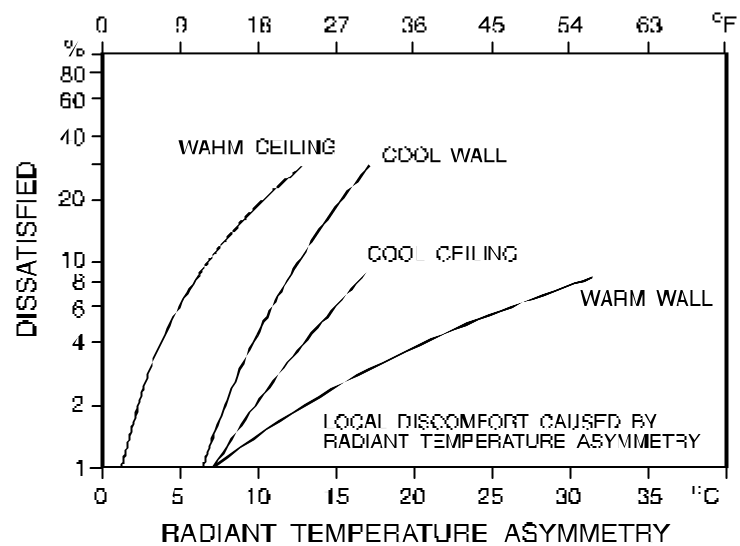
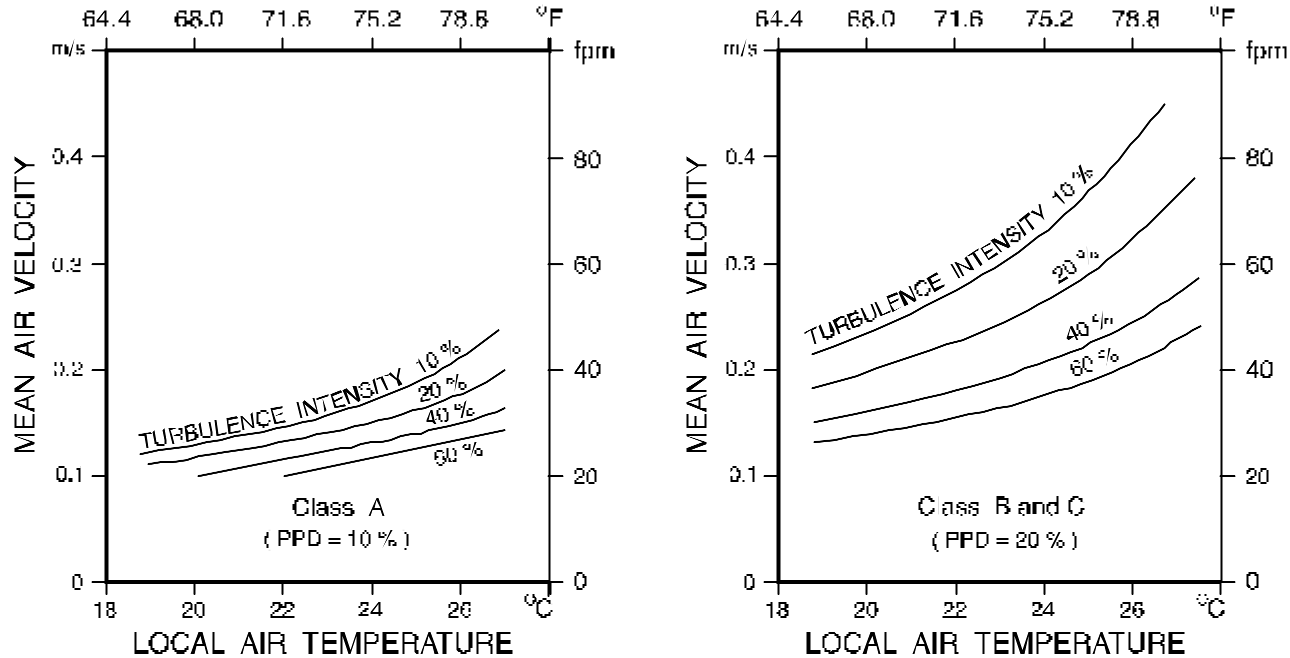



***Figure 5.4.2.1-1.*** *Local thermal discomfort caused by radiant asymmetry.*

The limits for radiant temperature asymmetry are specified in Table 5.2.4.1-1. Alternatively, Figure 5.4.2.1-1 may be used in conjunction with the PPD limits from Table 5.2.4-1 to determine the allowable radiant asymmetry.

*TABLE 5.2.4.1-1. Allowable radiant temperature asymmetry for the three classes of thermal environment.*

| Category | Radiant temperature asymmetry ° C (°F) | | | |
|---|---|---|---|---|
| | Warm ceiling | Cool wall | Cool ceiling | Warm wall |
| A | < 5 (9) | < 10 (18) | < 14 (25.2) | < 23 (41.4) |
| B | < 5 (9) | < 10 (18) | < 14 (25.2) | < 23 (41.4) |
| C | < 7 (12.6) | < 13 (23.4) | < 18 (32.4) | < 35 (63) |




**5.2.4.2. Draft**

Draft is unwanted local cooling of the body caused by air movement. Draft sensation depends on the air speed, the air temperature, the turbulence intensity, the activity, and the clothing. Sensitivity to draft is greatest where the skin is not covered by clothing, especially the head region comprising the head, neck and shoulders and the leg region comprising the ankles, feet and legs. The requirements in Section 5.2.4.2 are based on sensitivity to draft in the head region with airflow from behind and may be conservative for some locations on the body and for some directions of airflow.

***Figure 5.4.2.1.-1.*** *Allowable mean air speed as a function of air temperature and turbulence intensity for Class A and Class B thermal environments. Class C is the same as Class B.*

The maximum allowable air speed for each class of environment is specified in Figure 5.2.4.2.1 as a function of air temperature and turbulence intensity. Alternatively, the following equation may be used for determining the maximum allowable air speed. The predicted percentage of people dissatisfied (PPD) due to annoyance by draft is given by

```
PPD=((34-ta)*(v-0.05)^0.62)*(0.37*v*Tu+3.14)
```

where: PPD is the percentage of people dissatisfied due to draft;

$t_a$ is the local air temperature in degree Celsius;
v is the local mean air speed in m/s;
Tu is the local turbulence intensity in percent.

For $t_a$ in degree F, v in fpm and Tu in %:

$$PPD=((93.2-t_a)*(v-10)^{0.62})*(0.00004*v*Tu + 0.066)$$

For v< 0.05 m/s (10 fpm) use v=0.05 m/s (10 fpm).
For PPD>100%, use PPD=100%.

The values of PPD predicted from this equation must be within the limits specified for draft in Table 5.2.4-1. On average the turbulence intensity in a large part of the occupied zone of rooms with mixing ventilation is around 35% and 20% in rooms with displacement ventilation or without mechanical ventilation. These values may be used in the above equation when the turbulence intensity is not measured.

The criteria specified in Section 5.2.4.2 do not apply to the use of elevated air speed in Section 5.2.3. However, when occupants choose to turn off the elevated air speed, these criteria apply.

### 5.2.4.3. Vertical air temperature difference

Thermal stratification that results in the air temperature at the head level being warmer than at the ankle level may cause thermal discomfort. This section specifies allowable differences between the air temperature at head level and the air temperature at ankle level. Thermal stratification in the opposite direction is rare, is perceived more favorably by occupants, and is not addressed in this standard.

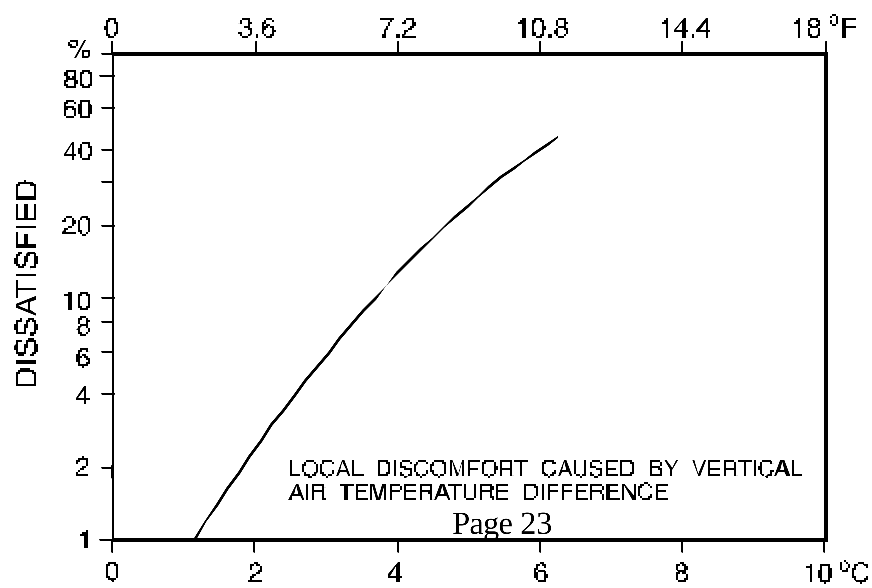


***Figure 5.2.4.3-1.*** *Local thermal discomfort caused by vertical temperature differences.*

The allowable differences in air temperature from the ankle level to the head level may be determined from Table 5.2.4.3-1. Alternatively, Figure 5.2.4.3-1 may be used in conjunction with the PPD limits for vertical temperature differences in Table 5.2.4-1 to determine the allowable differences in air temperature from the ankle level to the head level.

*TABLE 5.2.4.3-1. Allowable vertical air temperature difference between head and ankles for the three classes of thermal environment.*

| Class | Vertical air temperature difference °C (F°) |
|---|---|
| A | < 2 (< 3.6) |
| B | < 3 (< 5.4) |
| C | < 4 (< 7.2 ) |

### 5.2.4.4. Floor surface temperature

Occupants may feel uncomfortable due to contact with floor surfaces that are too warm or too cool. The temperature of the floor, rather than the material of the floor covering, is the most important factor for foot thermal comfort for people wearing shoes. The criteria in Section 5.2.4.4 are based on people wearing lightweight indoor shoes. These criteria may also be used for people wearing heavier footgear but may be conservative. This standard does not address the floor temperature required for people not wearing shoes. This standard does not address acceptable floor temperatures when people sit on the floor.

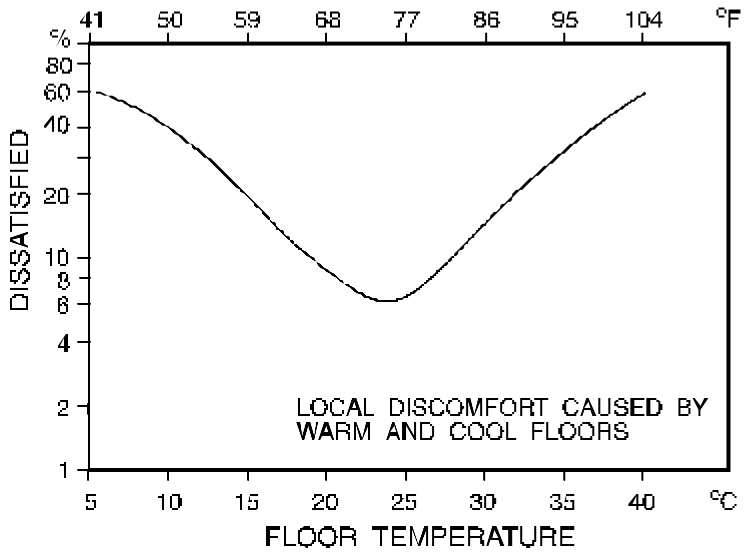



***Figure 5.2.4.4-1.*** *Local discomfort caused by warm and cool floors.*

The limits for floor temperature are specified in Table 5.2.4.4-1. Alternatively, Figure 5.2.4.4-1 may be used in conjunction with the PPD limits from Table 5.2.4-1 to determine the allowable floor temperature range.

*TABLE 5.2.4.4-1. Allowable range of the floor temperature for the three classes of the thermal environment.*

| Class | Range of surface temperature of the floor °C (°F) |
|---|---|
| A | 19 – 29 (66.2 - 84.2) |
| B | 19 - 29 (66.2 – 84.2) |
| C | 17 - 31 (62.6 - 87.8) |

## 5.2.5. Temperature variations with time

Fluctuations in the air temperature and/or mean radiant temperature may affect the thermal comfort of occupants. Those fluctuations under the direct control of the individual occupant do not have a negative impact on thermal comfort and the requirements of section 5.2.5 do not apply to these fluctuations. Fluctuations which occur

due to factors not under the direct control of the individual occupant (e.g. cycling from thermostatic control) may have a negative effect on comfort and the requirements of Section 5.2.5 do apply to these fluctuations. Fluctuations that occupants experinece as a result of moving between locations with different environmental conditions are allowed as long as the conditions at all of these locations are within the comfort zone for these moving occupants.

#### 5.2.5.1 Cyclic variations

Cyclic variations refer to those situations were the operative temperature repeatedly rises and falls and the period of these variations is not greater than 15 minutes. If the period of the fluctuation cycle exceeds 15 minutes, the variation is treated as a drift or ramp in operative temperature and the requirements of Section 5.2.5.2 apply. In some situations, variations with a period not greater than 15 minutes are superimposed on variations with a longer period. In these situations, the requirements of Section 5.2.5.1 apply to the component of the variation with a period not greater than 15 minutes and the requirements of section 5.2.5.2 apply to the component of the variation with a period greater than 15 minutes.

Table 5.2.5.1-1 specifies the maximum allowable peak-to-peak cyclic variation in operative temperature for each class of thermal environment.

*Table 5.2.5.1-1. Allowable cyclic operative temperature variation.*

| Class of Thermal Environment | Allowable Peak-to-Peak Variation in Operative Temperature, $^{o}$C ($^{o}$F) |
|---|---|
| Class A | 0.8 (1.5) |
| Class B | 1.1 (2.0) |
| Class C | 1.4 (2.5) |

#### 5.2.5.2 Drifts or ramps

Temperature drifts and ramps are monotonic, non-cyclic changes in operative temperature. The requirements of this section also apply to cyclic variations with a period greater than 15 minutes. Generally, drifts refer to passive temperature changes of the

enclosed space, and ramps refer to actively controlled temperature changes. The requirements of this section are the same for drifts and ramps. The requirements of this section apply to all three classes of thermal environment.

The rate of change in operative temperature during drifts or ramps may not exceed 0.6 °C/h (1.0 °F/h). Drifts or ramps are allowed without further restriction provided that the operative temperature does not go above or below the comfort zone limits. However, the operative temperature may go above or below the comfort zone limits during a drift or ramp provided the drift or ramp starts inside the comfort zone at an operative temperature at least 0.6°C (1.0°F) away from the limit that is exceeded, the maximum rate of change in operative temperature does not exceed 0.6°C/h (1.0°F/h), and the limits of the comfort zone are not exceeded for a period of more than 1.0 hour.

## 5.3 Optional Method for Determining Acceptable Thermal Conditions in Naturally Conditioned Spaces

For the purpose of this standard, naturally conditioned spaces are those spaces where the thermal conditions of the space are regulated primarily by the occupants through opening and closing of the windows. *Field experiments have shown that occupants' thermal responses in such spaces* depends in part on the outdoor climate, and *differs from thermal responses in buildings with centralized HVAC systems primarily because of the different thermal experiences, availability of control, and shifts in occupant expectations.* This optional method is intended for such spaces. In order for this optional method to apply, the space in question must be equipped with operable windows which open to the outdoors and which can be readily opened and adjusted by the occupants of the space. There must be no mechanical cooling system for the space (e.g. refrigerated air-conditioning, radiant cooling, or desiccant cooling). Mechanical ventilation with unconditioned air may be utilized, but opening and closing of windows must be the primary means of regulating conditions in the space. The space may be provided a heating system, but this optional method does not apply when the heating system is in operation. This optional method applies only to spaces where the occupants are engaged in near sedentary physical activities with metabolic rates ranging from 1.0 met to 1.3 met. See Appendix A for estimation of metabolic rates. This optional method applies only to spaces where the

occupants may freely adapt their clothing to the indoor and/or outdoor thermal conditions.

Allowable indoor operative temperatures for spaces that meet these criteria may be determined from Figure 5.3-1. This figure includes two sets of operative temperature limits, one for 80% acceptability and one for 90% acceptability. The 80% acceptability limits are for typical applications and should be used when other information is not available. The 90% acceptability limits may be used when a higher standard of thermal comfort is desired.

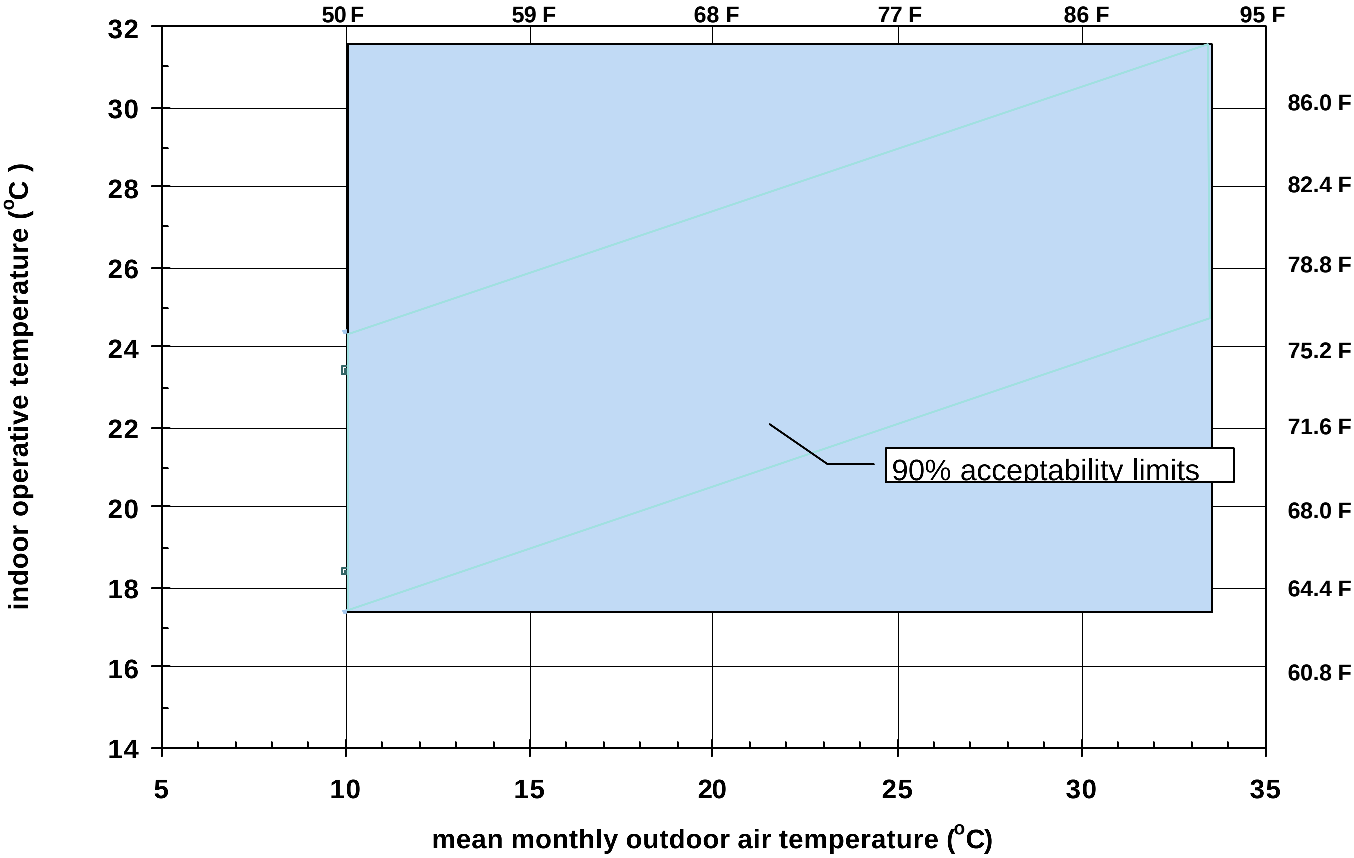



*Fig 5.3.1. Acceptable operative temperature ranges for naturally conditioned spaces.*

The allowable operative temperature limits in Figure 5.3-1 may not be extrapolated to outdoor temperatures above and below the end points of the curves in that figure. If the mean monthly outdoor temperature is less than 10°C (50°F) or greater than 33.5°C (92.3°F), this option may not be used and no specific guidance for naturally conditioned spaces is included in this standard.

Figure 5.3-1 accounts for local thermal discomfort effects in typical buildings and it is not necesarry to address these factors when using this option. However, if there is reason to believe that local thermal discomfort is a problem, the criteria in section 5.2.4 may be applied.

Figure 5.3-1 already accounts for people’s clothing adaption in naturally conditioned spaces by relating the acceptable range of indoor temperatures to the outdoor climate, and it is not necessary to estimate the clothing values for the space.

No humidity or air speed limits are required when this option is used.

## 5.4 Description of Thermal Environmental Variables

The following description of the environmental variables is for the purpose of understanding their use in Section 5. It is not intended to be a measurement specification. Section 7 specifies measurement requirements. If there is a discrepancy between the descriptions in Section 5.4 and the requirements in Section 7, then the requirements in Section 7 supercede the descriptions in Section 5.4 for the purpose of measurement.

For the purposes of Section 5, the thermal environment is defined with respect to the occupant.

**Air temperature** is the average temperature of the air surrounding an occupant. The average is with respect to location and time. As a minimum, the spatial average is the numerical average of the air temperature at the ankle level, the waist level and the head level. These levels are 0.1 m, 0.6 m and 1.1 m (4 in, 24 in and 43 in) respectively for seated occupants and 0.1 m, 1.1 m and 1.7 m (4 in, 43 in and 67 in) for standing occupants. Intermediate, equally spaced locations may also be included in the average. When the occupant is in a directed airflow, the air temperature on the upstream side should be used. As a minimum, the temporal average is a three-minute average with at least 18 equally spaced points in time. However, the period may extend up to 15 minutes to average cyclic fluctuations if necessary. The temporal average applies to all locations in the spatial average.

**Local air temperature** is defined in the same way as the air temperature except that it refers to a single level (e.g. head level). At least one location is required at this level. However, multiple locations around the body may be included to determine a better average.

**Mean radiant temperature** is defined as the temperature of a uniform, black enclosure that exchanges the same amount of thermal radiation with the occupant as the actual enclosure. It is a single value for the entire body and may be considered a spatial average of the temperature of surfaces surrounding the occupant weighted by their view factors with respect to the occupant. See Chapter 8, *ASHRAE Handbook of Fundamentals, 1997* for a more complete description of mean radiant temperature. For the purpose of Section 5, mean radiant temperature is also a time-averaged value. As a minimum, the temporal average is a three-minute average with at least 18 equally spaced points in time. However, the period may extend up to 15 minutes to average cyclic fluctuations if necessary.

**Operative temperature** is the average of the air temperature and the mean radiant temperature weighted respectively by the convection heat transfer coefficient and the linearized radiation heat transfer coefficient for the occupant. See Chapter 8, *ASHRAE Handbook of Fundamentals, 1997* for a more complete description of operative temperature. For occupants engaged in near sedentary physical activity (with metabolic rates between 1.0 met and 1.3 met), not in direct sunlight, and not exposed to air velocities greater than 0.20 m/s (40 fpm) the relationship can be approximated with acceptable accuracy by

$$T_o = (T_a + T_r) / 2$$

where

$T_o$ is the operative temperature,
$T_a$ is the air temperature, and
$T_r$ is the mean radiant temperature.

**Radiant asymmetry** is the difference between the plane radiant temperature in opposite directions. The plane radiant temperature is defined similarly to mean radiant temperature except that it is with respect to a small planar surface element exposed to the thermal radiation from surfaces from one side of that plane. The vertical radiant asymmetry is with plane radiant temperatures in the upward and downward direction. The horizontal radiant asymmetry is the maximum difference between opposite plane radiant temperatures for all horizontal directions. The radiant asymmetry is determined at the waist level, 0.6 m (24 in) for a seated occupant and 1.1 m (43 in) for a standing occupant. Time averaging for radiant asymmetry is the same as for mean radiant temperature. See Chapter 8, *ASHRAE Handbook of Fundamentals, 1997* for a more complete description of plane radiant temperature and radiant asymmetry.

**Floor temperature** is the surface temperature of the floor when it is in contact with the occupant's shoes. Since floor temperatures seldom change rapidly, time averaging does not need to be considered.

**Mean monthly outdoor temperature** is the arithmetic average of the means of the daily minimum and daily maximum temperature for the preceeding 30 days.

**Air speed** is the average speed of the air to which the body is exposed. The average is with respect to location and time. Time averaging and spatial averaging are the same as for air temperature. However, the time averaging period extends only to

three minutes. Variations that occur over a period greater than three minutes should be treated as two different air speeds.

**Turbulence intensity** is the ratio of the standard deviation of the airspeed with respect to time and the time-averaged airspeed. The turbulence intensity is primarily for the head/shoulder portions of the body, the 1.1 m (43 in) level for seated occupants and 1.7 m (67 in) level for standing occupants. It may also apply to the ankle/lower leg areas if they are not covered with clothing, the 0.1 m (4 in) level for both standing and seated occupants.

**Humidity** is a general reference to the moisture content of the air. It may be expressed in terms of several thermodynamic variables including vapor pressure, dew point temperature, and humidity ratio. It is spatially and temporally averaged in the same manner as air temperature.

# 6. Compliance

## 6.1 Design

The scope of this standard does not include specific guidance regarding mechanical systems, control systems, or the thermal envelopes for spaces. Building systems (combination of mechanical systems, control systems, and thermal envelopes must be designed so that, at design conditions, they are able to maintain the space at conditions within the range specified by one of the methods in this standard. Additionally, the mechanical systems, control systems, and thermal envelopes must be designed so that they are able to maintain the space at conditions within the range specified in this standard at all combinations of less extreme conditions which are expected to occur. The less extreme conditions include both internal loads and the external environment. The system should have controls that enable it to meet comfort requirements at less than full system capacity.

The method and design conditions appropriate for the intended use of the building shall be selected by the design team and owner (e.g. owner's agent, developer, or equivalent). Design conditions shall be documented per Section 6.1.1. Design conditions shall include an appropriate exceedence level.

*Design weather data are statistically based and established to explicitly acknowledge certain percentages of exceedence (i.e. 1% design 4 month summer basis. 29 hours of exceedence). This recognizes the impracticality of providing an HVAC system that can meet all loads under all weather or operating conditions encountered in its lifetime. Thus, in practice, the requirements of Section 5 may not be met during excursions from the design conditions. Also, weather based exceedence will usually be less than indicated by the exceedence percentage because other design loads will not often be concurrent. Because of differences in metabolic rates between individuals and the resultant differences in response to the environment, actual operating building temperatures cannot be specified in this standard.*

### 6.1.1 Documentation

Complete plans, descriptions, component literature, and operation and maintenance instructions for the building systems should be provided and maintained These should include, but not be limited to building system design specifications and design intent as follows: *note: some of the below sections may not be applicable to naturally ventilated buildings.*

1. The design criteria of the system in terms of indoor temperature and humidity, including any tolerance or range, based

on stated design outdoor ambient conditions and total indoor loads, should be stated in writing. Values assumed for comfort parameters, including clothing and metabolic rate, used in calculation of design temperatures, shall be clearly stated

2. The system input or output capacities necessary to attain the design indoor conditions at design outdoor ambient conditions should be stated in writing, as well as the full input or output capacities of the system as supplied and installed.

3. The limitations of the system to control the environment of the zone (s) should be stated in writing whether based on temperature, humidity, ventilation, time of week, time of day, or seasonal criteria.

4. The overall space supplied by the system should be shown in a plan view layout, with individual zones within it identified. All registers or terminal units should be shown and identified with type, flow, or radiant value.

5. Significant structural and decor items should be shown and identified if they affect indoor comfort Notes shall be provided to identify which areas within a space, and what locations relative to registers, terminal units, relief grills and control sensors shall not be obstructed as they would negatively affect indoor comfort.

6. Areas within any zone that lie outside the comfort control areas, where people should not be permanently located, should be identified.

7. Locations of all occupant adjustable controls should be identified, and each should be provided with a legend describing what zone (s) it controls, what function (s) it controls, how it is to be adjusted, the range of effect it can have, and the recommended setting for various times of day, season, or occupancy load.

8. If more than one comfort level is available for any zone (s), they should be identified as A, B, C etc., with A being the narrowest range (highest comfort), and the specifications as above shall be provided for each, along with the relative seasonal energy usage for each at 80 % of design ambient.

9. A control schematic should be provided in block diagram with sensors, adjustable controls, and actuators accurately identified for each zone. If zone control systems are independent but identical, one diagram is sufficient if identified for which zones

it applies. If zones are interdependent or inter-active, their control diagram should be shown in total on one block diagram with the point (s) of interconnection identified.

10. The general maintenance, operation and performance of the building systems should be stated in writing, followed by more specific comments on the maintenance and operation of the automatic controls and manually adjustable controls, and the response of the system to each. Where necessary, specific seasonal settings of manual controls should be stated, as also major system changeover that is required to be performed by a professional service agency shall be identified.

11. Specific limits in the adjustment of manual controls shall be stated. Recommendations for seasonal setting on these shall be stated along with the degree of manual change that should be made at any one time, and the waiting time between adjustments, in trying to fine tune the system. A maintenance and inspection schedule for all thermal environmental related building systems should be provided.

12. Locations of all occupant adjustable controls should be identified, and each should be provided with a legend describing what zone (s) it controls and what function (s) it controls.

13. Assumed electrical load for lighting and equipment in occupied spaces (including diversity considerations) used in HVAC load calculations should be documented, along with any other significant thermal and moisture loads assumed in HVAC load calculations and any other assumptions upon which HVAC and control design is based.

## 6.2 Commissioning

Commissioning should be performed per Section 7 to demonstrate that the building systems can be operated to meet the requirements of Section 5 according to the design intent and under design conditions inclusive of less severe conditions, as documented per Section 6.1.1.

## 6.3 Operation

Building systems should be operated as needed to provide an acceptable thermal environment as generally described by Section 5, except for a percentage of time corresponding to the design weather exceedence described in design documentation (see Section 6.1.1). Because of differences in metabolic rate and clothing

from that of the design, operating temperatures in a building cannot be specified in this standard. Rather, the building shall be operated in such a manner that the majority of occupants consider the temperature setpoints to be acceptable, and that the building systems can maintain those setpoints within the tolerances specified in the design.

*Guidance - Design conditions include the design weather conditions chosen by the engineer and owner as appropriate for the intended use of the building. Design weather data are statistically based and established to explicitly acknowledge certain percentages of exceedence (i.e. 1% design, 4 month summer basis. 29 hours of exceedence). This recognizes the impracticality of providing an HVAC system that can meet all loads under all weather or operating conditions encountered in its lifetime. Thus, in practice the requirements of Section 5 may not be met during the number of hours equivalent to the design weather data exceedence percentage. Weather based exceedence will usually be less than indicated by the exceedence percentage because other design loads will not often be concurrent. However, other reasonable circumstances involving loads or malfunctions may also result in excursions. The total allowable excursions can include such circumstance. Discretional differences between occupants, and differences in clothing and activity will influence the set-point preference of the occupants. During operation of the system, the temperature ranges in Figure 5.2.1.1-1 should not be used as a "dictate". The people occupying a particular space at a particular time may happen to prefer a lower or a higher temperature level than shown in Figure 5.2.1.1-1. A temperature level should of course be selected to minimize the discomfort among the actual users*

### 6.3.1 Reconstruction

Operation should maintain an acceptable thermal environment during periods when an occupied building is under reconstruction.

*No special allowance should be given for circumstances involving construction activities on an occupied building. However, excursions resulting from construction activities can be part of the limited allowed exceedence.*

### 6.3.2 Alterations or Change of Use

Design or operation of systems should be changed as necessary to accommodate changes in building use or occupancy category, significant long-term changes in occupancy density, or other

changes which affect the ability of building systems to meet provide an acceptable thermal environment.

*Modification of building systems or control is often necessary to maintain the thermal environment when spaces are altered or occupancy is changed.*

### 6.3.3 Pre-occupancy Operation

Operation during unoccupied periods should be necessary and sufficient to enable an acceptable thermal environment during occupied hours.

### 6.3.4 Maintenance

Building system components should be inspected, adjusted, cleaned, calibrated, or replaced as needed to assure proper operation and maintenance of an acceptable thermal environment. These components should include but not be limited to building envelope components, air filters and filter seals, heating and cooling coils, cooling towers, reheat coils, fan motor belts, humidifiers, thermostats, control devices, and sensors. A schedule should be established and maintained for this inspection and maintenance. This schedule should be documented per section 6.1.1.

# 7. Evaluation of the Thermal Environment.

*At the design stage the thermal environment may be evaluated by calculations. Simple hand calculations and computer models of buildings and systems are available for this purpose.*
*In existing buildings, full-scale laboratory testing, by commissioning and during operation the thermal environment may by evaluated based on measurements.*

## 7.1 Measuring device criteria

The measuring instrumentation used shall meet the requirements to measuring range and accuracy given in ASHRAE Standard 70-90, 113-90 or ISO7726, and the referenced source shall be so identified.

*Guidance- The referenced ASHRAE standards allow a different specification for measurement of air speed than the ISO standard, depending on whether turbulence intensity is to be measured. Instruments with not sufficiently short time constant can be used to measure average speed but not turbulence intensity. When no measurement of turbulence intensity is required, the time constant of the device used to measure air speed is allowed to be longer.*

## 7.2 Measurement positions

### 7.2.1 Location of measurements.

Measurements shall be made in occupied zones of the building at locations where the occupants are known to or expected to spend their time.

*Such locations might be workstation or seating areas, depending on the function of the space. In occupied rooms, measurements should be taken at a representative sample of occupant locations spread throughout the occupied zone. In unoccupied rooms, the evaluator should make a good faith estimate of the most significant future occupant locations within the room and make appropriate measurements.*

If occupancy distribution cannot be estimated, then the measurement locations shall be as follows:

**(a)** in the center of the room or zone

**(b)** 1.0 m (2 ft) inward from the center of each of the room's walls.

In the case of exterior walls with windows, the measurement location should be 1.0 m (2 ft) inward from the center of the largest window.

*In either case, measurements should be taken in locations where the most extreme values of the thermal parameters are estimated or observed to occur. Typical examples might be near windows, diffuser outlets, corners, and entries. Measurements are to be made sufficiently away from the boundaries of the occupied zone and from any surfaces to allow for proper circulation around measurement sensors with positions as described below.*

Absolute humidity need only be determined at one location in each occupied room or HVAC controlled zone.

### 7.2.2 Height above floor of measurements

Air temperature and air speed shall be measured at the 0.1, 0.6 and 1.1 m (4, 24 and 43 in.) levels for sedentary occupants at the locations specified in Section 7.2.1. Standing activity measurements shall be made at the 0.1, 1.1 and 1.7 m (4, 43 and 67 in.) levels.  Operative temperature or PMV-PPD shall be measured or calculated at the 0.6 m (24 in.) level for seated and 1.1 m (43 in.) level for standing occupants.

Radiant asymmetry shall be measured at the 0.6-m (24-in.) level for seated and 1.1 m (43 in.) for standing occupants. If desk-level furniture (which is in place) blocks the view of strong radiant sources and sinks, the measurements are to be taken above desktop level.  Floor surface temperatures are to be measured with the anticipated floor coverings installed. Humidity shall be measured within the occupied zone.

## 7.3 Measurement Periods

### 7.3.1 Air speed

The measuring period for determining the average air speed at any location shall be 3 minutes.  Turbulence intensity is measured in the same period by calculating the ratio of the standard deviation for the period to the average air speed. (See Section 3 for definition of response time and its relation to the time constant.)

### 7.3.2 Temperature cycles and drifts

For determining compliance with the nonsteady state requirements of Section 5, the rate of change of operative temperature is used. It is the difference between maximum and minimum operative temperatures measured during the same cycle divided by the elapsed time, in minutes:

Rate of change (degrees/h) = 60($t_o$ max - $t_o$ min.) / time (minutes)

The measurements shall be made every five minutes or less for at least two hours to establish the nature of the temperature cycle. The use of an automatic recorder is the preferred method of measurement; however it is possible to make the measurements required in this section without the use of recording equipment.

### 7.3.3 Clothing and Activity

In buildings, it may be appropriate to measure the clothing and activity levels of the occupants. These shall be estimated in the form of mean values over a period of 0.5 to 1.0 hour prior to measuring the thermal parameters.

## 7.4 Measuring Conditions

In order to determine the effectiveness of the building system at providing the environmental conditions specified in Standard 55, measurements shall be made under the following conditions.

To test during the heating period (winter conditions), the measurements required shall be made when the indoor-outdoor temperature difference is not less than 50% of the difference used for design and with cloudy to partly cloudy sky conditions.

To test during the cooling period (summer conditions) the measurements required shall be made when the outdoor-indoor temperature difference and humidity difference are not less than 50% of the differences used for design and with clear to partly cloudy sky conditions.

To test interior zones of large buildings, the measurements required shall be made with the zone loaded to at least 50% of the design load for at least one complete cycle of the HVAC system, if not proportionally controlled. Simulation of heat generated by occupants is recommended.

## 7.5 Mechanical Equipment Operating Conditions

In order to determine appropriate corrective actions following the use of Standard 55 to analyze the environment, the following operations of the mechanical system should be measured concurrently with the environmental data.

- Air supply rate into the space being measured
- Room/supply air temperature differential
- Type and location of room diffuser or air outlet
- Discharge air speed
- Perimeter heat type, location and status
- Return grille location and size
- Type of air supply system, if known
- Surface temperatures of heated or cooled surfaces
- Water supply and return temperatures of hydraulic systems.

## 7.6 Commissioning the Thermal Environment

### 7.6.1 Define Criteria

Before commissioning a thermal environment, the comfort criteria, specified by the design engineer and the owner, must be defined and in writing. From this definition, the commissioning team will evaluate the system's ability to meet and maintain the desired comfort level(s). The comfort criteria definition must outline, but not be limited to, the following:

- Temperature (air, radiant, surface)
- Humidity
- Air speed

The environmental conditions must be specified as well to ensure measurements taken correspond correctly to the design parameters. Environmental conditions required are, but again not limited to, the following:

- Outdoor temperature design conditions
- Outdoor humidity design conditions
- Clothing (seasonal)
- Activity expected

## 7.6.2 Commissioning Methods

In order to determine the thermal environments ability to meet the defined criteria, as outlined in Section 7.6.1 above, there are two methods which can be implemented. The first method of environment commissioning is to statically determine occupant satisfaction through the evaluation of survey results. The second is to technically establish comfort conditions through the analysis of environment variables.

### 7.6.2.1 Survey Occupants

The purpose of ASHRAE Standard 55, is to ensure a room, building, etc, is comfortable for the majority (at least 80%) of the occupants. Therefore, an effective way to evaluate the environmental conditions is to survey the occupants. This survey should be performed for every operating mode, in every design condition. This would require a survey check sheet to be provided by the team responsible for the commissioning of the space. The sheet shall have, as a minimum, the following data for the occupant to fill in:

- Occupants name, date & time
- Approximate outside air temperature
- Clear sky/ Overcast (if applicable)
- Seasonal conditions
- Occupant’s clothing
- Occupant’s activity level
- Applicable Equipment
- General Thermal Comfort level
- Occupant’s location

In addition to the occupant’s data, space should be provided for the surveyor to number the survey, summarize the results and sign his/her name.

### 7.6.2.2 Analyze Environment Variables

The second method for evaluating the comfort conditions is to analyze specific environmental data for compliance with the design criteria. Each application of commissioning for thermal comfort is unique. A specific test plan will be required to accommodate the project scope.

Assess the environment for which comfort conditions are going to be verified. Determine the need to verify floor surface temperature, vertical temperature difference and radiant temperature asymmetry.

When this need exists, it is important to ensure the maximum potential for variance is exploited. (i.e. take radiant asymmetry temperature reading on a sunny day with the blinds open.)

Under all circumstances air speed (non-directional), air temperature and humidity shall be verified.

- Verify satisfactory air speed with a group of readings taken at a strategic location with in the space. For VAV systems, readings shall be taken at maximum flow with minimum supply air temperature.
- Determine the ideal location for providing accurate air temperature and humidity readings. Proof of performance for both air temperature and humidity shall require trended data.

Where variables are going to be trended, successful comfort control shall be a function of steady state performance. Steady state shall require the trended variable remain within a specified range without cycling. Cycling is defined as fluctuation over 50% of the specified range every 15 minutes. This verification shall include trending variables for at least one occupied cycle during each seasonal condition.

## 7.6.3 Documentation

The effort of commissioning also involves ensuring a thoroughly documented process. Which ever method of thermal environment commissioning is chosen, the process must be well documented and turned over to the design engineer and the owner for approval and for their records.

### 7.6.3.1 Documenting Surveys

When surveying the occupants of a building, as outlined in section 9.6.2.1, the survey method must be developed, written, and turned over, with the sample survey sheets to the design engineer and the owner for review and approval. At the completion of the survey, the survey sheets and analysis of the data shall be turned over to the design engineer and the owner for review and sign-off of the commissioning process.

**7.6.3.2 Documenting Variable Analysis**

For analysis of the environmental variables outlined in Section 9.2.2, the trend logs and data analysis must be submitted for review by the design engineer and the owner. Again, the method of trending must be included with this submission if it has not been provided prior to commissioning for approval.

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[1] *When thermal conditions in the occupied zone have a high sensitivity to time of day and weather conditions, the measurement shall be made such that the high and low extremes of the thermal parameters are determined.*
*ASHRAE Standard 113-1990 offers a procedure for determining air speed and temperature variations in building spaces, and provides additional guidance for the measurement of mechanical equipment parameters.*

Appendix A
Activity levels
This appendix is informative

Metabolic Rates for Typical Tasks

| Activity | Metabolic Rate met units | $W/m^2$ | $(BTU/h \cdot ft^2)$ |
|---|---|---|---|
| **Resting** | | | |
| Sleeping | 0.7 | 40 | (13) |
| Reclining | 0.8 | 45 | (15) |
| Seated, quiet | 1.0 | 60 | (18) |
| Standing, relaxed | 1.2 | 70 | (22) |
| **Walking (on level surface)** | | | |
| 0.9 m/s, 3.2 km/h, 2.0 mph | 2.0 | 115 | (37) |
| 1.2 m/s, 4.3 km/h, 2.7 mph | 2.6 | 150 | (48) |
| 1.8 m/s, 6.8 km/h, 4.2 mph | 3.8 | 220 | (70) |
| **Office Activities** | | | |
| Seated, reading or writing | 1.0 | 60 | (18) |
| Typing | 1.1 | 65 | (20) |
| Filing, seated | 1.2 | 70 | (22) |
| Filing, standing | 1.4 | 80 | (26) |
| Walking about | 1.7 | 100 | (31) |
| Lifting/packing | 2.1 | 120 | (39) |
| **Driving/Flying** | | | |
| Automobile | 1.0-2.0 | 60-115 | (18-37) |
| Aircraft, routine | 1.2 | 70 | (22) |
| Aircraft, instrument landing | 1.8 | 105 | (33) |
| Aircraft, combat | 2.4 | 140 | (44) |
| Heavy vehicle | 3.2 | 185 | (59) |
| **Miscellaneous Occupational Activities** | | | |
| Cooking | 1.6-2.0 | 95-115 | (29-37) |
| House cleaning | 2.0-3.4 | 115-200 | (37-63) |
| Seated, heavy limb movement | 2.2 | 130 | (41) |
| Machine work | | | |
| sawing (table saw) | 1.8 | 105 | (33) |
| light (electrical industry) | 2.0-2.4 | 115-140 | (37-44) |
| heavy | 4.0 | 235 | (74) |
| Handling 50 kg (100 lb) bags | 4.0 | 235 | (74) |
| Pick and shovel work | 4.0-4.8 | 235-280 | (74-88) |
| **Miscellaneous Leisure Activities** | | | |

| | | | |
|---|---|---|---|
| Dancing, social | 2.4-4.4 | 140-255 | (44-81) |
| Calisthenics/exercise | 3.0-4.0 | 175-235 | (55-74) |
| Tennis, singles | 3.6-4.0 | 210-270 | (66-74) |
| Basketball | 5.0-7.6 | 290-440 | (92-140) |
| Wrestling, competitive | 7.0-8.7 | 410-505 | (129-160) |

# Use of Metabolic Rate Data

These data are reproduced from Chapter 8 of the *1997 ASHRAE Handbook, Fundamentals*. This handbook chapter provides additional information for estimating and measuring activity levels. General guidelines for the use of these data follow.

Every activity that may be of interest is not included in this table. Users of this standard should use their judgement to match the activities being considered to comparable activities in the table. Some of the data in this table are reported as a range and some as a single value. The format for a given entry is based on the original data source and is **not** an indication of when a range of values should or should not be utilized. For all activities except sedentary activities, the metabolic rate for a given activity is likely to have a substantial range of variation that depends on the individual performing the task and the circumstances under which the task is performed.

A time-weighted average metabolic rate may be used for individuals with activities that vary over a period of one hour or less. For example, a person that typically spends 30 minutes out of each hour "lifting/packing," 15 minutes "filing, standing," and 15 minutes "walking about" has an average metabolic rate of 0.50x2.1+0.25x1.4+0.25x1.7=1.8 met. Such averaging should not be applied when the period of variation is greater than one hour. For example, a person that is engaged in "lifting/packing" for one hour and then "filing, standing" the next hour should be treated as having two distinct metabolic rates.

As metabolic rates increase above 1.0 met, the evaporation of sweat becomes a more and more important factor for thermal comfort. The PMV method does not fully account for this factor and this standard should not be applied to situations where the time-averaged metabolic rate is above 2.0 met. Typically, rest breaks (scheduled or hidden) or other operational factors (get parts, move products, etc.) combine to limit time-weighted metabolic rates to about 2.0 met in most applications.

Time averaging of metabolic rates only applies to an individual. The metabolic rates associated with the activities of various individuals in a space may **not** be averaged to find a single, average metabolic rate to be applied to that space. The range of activities of different individuals in the space and the environmental conditions required for those activities should be considered in applying this standard. For example, the customers in a restaurant may have a metabolic rate near 1.0 met while the servers may have metabolic rate closer to 2.0 met. Each of these groups of occupants should be considered separately in determining the conditions required for comfort.

Appendix B
Clothing insulation
: This appendix is normative

The amount of thermal insulation worn by a person has a substantial impact on thermal comfort and is an important variable in applying this standard. Clothing insulation is expressed in a number of forms. In this standard, the clothing insulation of an ensemble expressed as a clo-value ($I_{cl}$) is used. Users not familiar with clothing insulation terminology are referred to Chapter 8, *ASHRAE Handbook, Fundamentals* for more information.

The insulation provided by clothing can be determined by a variety of means and if accurate data are available from other sources, such as measurement with thermal manikins, those data may be used. When such information is not available, the tables in this appendix may be used to estimate clothing insulation using one of the methods described below. Regardless of the source of the clothing insulation value, this standard should not be used with clothing ensembles with more than 1.5 clo of insulation. Also, this standard should not be used with clothing that is highly impermeable to moisture transport (e.g. chemical protective clothing, rain gear, etc.).

Three methods for estimating clothing insulation are presented. The methods are listed in order of accuracy and should be used in this order of preference.

**Method 1:** Table B1 lists the insulation provided by a variety of common clothing ensembles. If the ensemble in question matches reasonably well with one of the ensembles in this table, then the indicated value of $I_{cl}$ should be used.

**Method 2:** Table B2 presents the thermal insulation of a variety of individual garments. These garments may be added to or subtracted from the ensembles in Table B1 to estimate the insulation of ensembles that differ in garment composition from those in Table B1. For example, if long underwear bottoms are added to Ensemble 5 in Table B1, the insulation of the resulting ensemble is estimated as $I_{cl}$ = 1.01 clo + 0.15 clo = 1.16 clo.

**Method 3:** A complete clothing ensemble may be defined using a combination of the garments listed in Table B2. The insulation of the ensemble is estimated as the sum of the individual values listed in Table B2. For example, the estimated insulation of an ensemble consisting of overalls

worn with a flannel shirt, T-shirt, briefs, boots, and calf-length socks is $I_{cl}$ = 0.30 + 0.34 + 0.08 + 0.04 + 0.10 + 0.03 = 0.89 clo.

Tables B1 and B2 are for a standing person. A sitting posture results in a decreased thermal insulation due to compression of air layers in the clothing. This decrease may be offset by insulation provided by the chair. Table B3 shows the net effect on clothing insulation for typical indoor clothing ensembles that results from sitting in a chair. These data may be used to adjust clothing insulation calculated using any of the above methods. For example, the clothing insulation for a person wearing Ensemble 3 from Table B1 sitting in an executive chair is 0.96 clo + 0.14 clo = 1.10 clo. For many chairs, the net effect of sitting is a minimal change in clothing insulation. For this reason, it is recommended that no adjustment be made to clothing insulation if there is uncertainty as to the type of chair and/or if the activity for an individual includes both sitting and standing.

Tables B1 and B2 are for a person that is not moving. Body motion decreases the insulation of a clothing ensemble by pumping air through clothing openings and/or causing air motion within the clothing. This effect varies considerably depending on the nature of the motion (e.g. walking versus lifting) and the nature of the clothing (stretchable and snug fitting versus stiff and loose fitting). Because of this variability, accurate estimates of clothing insulation for an active person are not available unless measurements are made for the specific clothing under the conditions in question (e.g. with a walking manikin). A rough estimate of the clothing insulation for an active person is:

$$I_{cl,\ active} = I_{cl} \times (0.6 + 0.4/M) \qquad 1.2\ \text{met} < M < 2.0\ \text{met}$$

where M is the metabolic rate in met units and $I_{cl}$ is the insulation without activity. For metabolic rates less than or equal to 1.2 met, no adjusted is recommended.

When sleeping or resting in a reclining posture, the bed and bedding may provide considerable thermal insulation. It is not possible to determine the thermal insulation for most sleeping or resting situations unless the individual is immobile. Individuals will adjust the bedding so as to suit individual preferences. Provided adequate bedding materials are available, the thermal environmental conditions desired for sleeping and resting vary considerably from person to person and cannot be determined by the methods included in this standard.

Clothing variability amongst occupants in a space is an important consideration in applying this standard. This variability takes two forms. In the first form, different individuals wear different clothing due to factors unrelated to the thermal conditions. Examples include different clothing style preferences for men and women, and offices where managers are expected to wear suits while other staff members may work in shirtsleeves. In the second form, the variability results from adaptation to individual differences in response to the thermal environment. For example, some individuals may wear a sweater while others wear short-sleeve shirts in the same environment, if there are no other constraints limiting what is worn. The first form of variability may result in differences in the requirements for thermal comfort between the different occupants and these differences should be addressed in applying this standard. In this situation, it is **not** acceptable to determine the average clothing insulation of various groups of occupants to determine the thermal environmental conditions needed for all occupants. Each group must be considered separately. Where the variability within a group of occupants is of the second form and is a result only of individuals freely making adjustments in clothing to suit their individual thermal preferences, it is acceptable to use a single representative average clothing insulation value for everyone in that group.

For near sedentary activities where the metabolic rate is approximately 1.2 met, the effect of changing clothing insulation on the optimum operative temperature is approximately 6°C (11°F) per clo. For example, Table B2 indicates that adding a thin, long-sleeve sweater to a clothing ensemble increases clothing insulation be approximately 0.25 clo. Adding this insulation would lower the optimum operative temperature by approximately 6 °C/clo x 0.25 clo = 1.5°C (11°F/clo x 0.25 clo = 2.8°F). The effect is greater with higher metabolic rates.

**Table B1. Clothing Insulation Values for Typical Ensembles [a]**

| Clothing Description | Garments Included [b] | $I_{cl}$ (clo) |
|---|---|---|
| **Trousers** | 1) Trousers, short-sleeve shirt | 0.57 |
| | 2) Trousers, long-sleeve shirt | 0.61 |
| | 3) #2 plus suit jacket | 0.96 |
| | 4) #2 plus suit jacket, vest, T-shirt | 1.14 |
| | 5) #2 plus long sleeve sweater, T-shirt | 1.01 |
| | 6) #5 plus suit jacket, long underwear bottoms | 1.30 |
| **Skirts/Dresses** (sandals) | 7) Knee-length skirt, short-sleeve shirt | 0.54 |
| | 8) Knee-length skirt, long-sleeve shirt, full slip | 0.67 |
| | 9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater | 1.10 |
| | 10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket | 1.04 |
| | 11) Ankle-length skirt, long-sleeve shirt, suit jacket | 1.10 |
| **Shorts** | 12) Walking shorts, short-sleeve shirt | 0.36 |
| **Overalls/Coveralls** | 13) Long-sleeve coveralls, T-shirt | 0.72 |
| | 14) Overalls, long-sleeve shirt, T-shirt | 0.89 |
| | 15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms | 1.37 |
| **Athletic** | 16) Sweat pants, long-sleeve sweatshirt | 0.74 |
| **Sleepwear** | 17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks) | 0.96 |

a) Data are from Chapter 8, *1997ASHRAE Handbook, Fundamentals.*
b) All clothing ensembles, except where otherwise indicated in parentheses, include shoes, socks, and briefs or panties. All skirt/dress clothing ensembles include panty hose and no additional socks.

## Table B2 Garment Insulation [a]

| **Garment Description** [b] | $I_{clu}$ **(clo)** | **Garment Description** [b] | $I_{clu}$ **(clo)** |
|---|---|---|---|
| **Underwear** | | **Dress and Skirts** [c] | |
| Bra | 0.01 | Skirt (thin) | 0.14 |
| Panties | 0.03 | Skirt (thick) | 0.23 |
| Men's briefs | 0.04 | Sleeveless, scoop neck (thin) | 0.23 |
| T-shirt | 0.08 | Sleeveless, scoop neck (thick), i.e., jumper | 0.27 |
| Half-slip | 0.14 | Short-sleeve shirtdress (thin) | 0.29 |
| Long underwear bottoms | 0.15 | Long-sleeve shirtdress (thin) | 0.33 |
| Full slip | 0.16 | Long-sleeve shirtdress (thick) | 0.47 |
| Long underwear top | 0.20 | Sweaters | |
| Footwear | | Sleeveless vest (thin) | 0.13 |
| Ankle-length athletic socks | 0.02 | Sleeveless vest (thick) | 0.22 |
| Pantyhose/stockings | 0.02 | Long-sleeve (thin) | 0.25 |
| Sandals/thongs | 0.02 | Long-sleeve (thick) | 0.36 |
| Shoes | 0.02 | Suit Jackets and Vests [d] | |
| Slippers (quilted, pile lined) | 0.03 | Sleeveless vest (thin) | 0.10 |
| Calf-length socks | 0.03 | Sleeveless vest (thick) | 0.17 |
| Knee socks (thick) | 0.06 | Single-breasted (thin) | 0.36 |
| Boots | 0.10 | Single-breasted (thick) | 0.42 |
| Skirts and Blouses | | Double-breasted (thin) | 0.44 |
| Sleeveless/scoop-neck blouse | 0.13 | Double-breasted (thick) | 0.48 |
| Short-sleeve knit sport shirt | 0.17 | Sleepwear and Robes | |
| Short-sleeve | 0.19 | Sleeveless short gown | 0.18 |

| | | | |
|---|---|---|---|
| dress shirt | | (thin) | |
| Long-sleeve dress shirt | 0.25 | Sleeveless long gown (thin) | 0.20 |
| Long-sleeve flannel shirt | 0.34 | Short-sleeve hospital gown | 0.31 |
| Long-sleeve sweatshirt | 0.34 | Short-sleeve short robe (thin) | 0.34 |
| Trousers and Coveralls | | Short-sleeve pajamas (thin) | 0.42 |
| Short shorts | 0.06 | Long-sleeve long gown (thick) | 0.46 |
| Walking shorts | 0.08 | Long-sleeve short wrap robe (thick) | 0.48 |
| Straight trousers (thin) | 0.15 | Long-sleeve pajamas (thick) | 0.57 |
| Straight trousers (thick) | 0.24 | Long-sleeve long wrap robe (thick) | 0.69 |
| Sweatpants | 0.28 | | |
| Overalls | 0.30 | | |
| Coveralls | 0.49 | | |

a) Data are from Chapter 8, *1997ASHRAE Handbook, Fundamentals.*
b) "Thin" refers to garments made of lightweight, thin fabrics often worn in the summer; "thick" refers to garments made of heavyweight, thick fabrics often worn in the winter.
c) Knee-length dresses and skirts.
d) Lined vests.

**Table B3. Typical Effect of Sitting on Clothing Insulation** [a]

| | |
|---|---|
| Net Chair [b] | -0.15 clo |
| Metal Chair | -0.08 clo |
| Wooden Stool | -0.03 clo |
| Office Chair | +0.09 clo |
| Executive Chair | +0.14 clo |

a) Valid for clothing ensembles with standing insulation values 0.5 clo < $I_{cl}$ < 1.2 clo. See *McCulough, E.A., B..W.Olesen and S.Hong (1994) Thermal insulation provided by chairs". ASHRAE Transaction, V100 (1), pp.795-802* for more detailed information.
b) A chair constructed from thin, widely spaced cords which provides no thermal insulation. Included for comparison purposes only.

Appendix C
Acceptable Approximation for Operative Temperature
: This appendix is informative

The assumption that operative temperature equals air temperature is acceptable when:

1. There is no radiant heating or cooling system, and
2. The average U value of the outside window/wall is less than

$$U_w < \frac{50}{t_{d,i} - t_{d,e}}$$

Where:

| | | |
|---|---|---|
| $U_w$ | Average U value of window/wall, | (W/m” · K) |
| $t_{d,i}$ | Internal design temperature, | °C |
| $t_{d,e}$ | External design temperature, | ° C |

3. Window solar heat gain coefficients (SHGC) are less than 0.48.

4. There is no major heat generating equipment in the space.

**Calculation of the operative temperature based on air- and mean radiant temperature**
In most practical cases where the relative air speed is small (< 0.2 m/s, 40 fpm) or where the difference between mean radiant and air temperature is small (< 4 °C, 7°F) the operative temperature can be calculated with sufficient approximation as the mean value of air and mean radiant temperature.

For higher precision and other environments the following formula may be used:

$t_{op} = A\ t_a + (1 - A)\ t_r$

where
$t_{op}$ is the operative temperature,
$t_a$ is the air temperature,
$t_r$ is the mean radiant temperature, and
the value of A can be found from the values below as a function of the relative air speed,
$v_r$

| | | | |
|---|---|---|---|
| $v_r$ | < 0.2 m/s | 0.2 to 0.6 m/s | 0.6 to 1.0 m/s |

| | (<40 fpm) | (40 to 120 fpm) | (120 to 200 m/s) |
|---|---|---|---|
| A | 0.5 | 0.6 | 0.7 |

Appendix D:
COMPUTER PROGRAM FOR CALCULATION OF PMV-PPD
: This appendix is normative

**From ASHRAE Thermal Comfort program help file:**

```
//Calculates PMV and PPD Based on I S O Standard 7730

{    float ICL, TCL, M, W, Tolerance, MW, FCL, FCIC, P1, P2, P3,
P4;
     float TAA, TRA, TCLA, TCLN, XF, XN, HC, HCN, HCF;
    float PM1, PM2, PM3, PM4, PM5, PM6, PressureInPascals;
    int nIterations;

    float AirVelocity = Conditions.AirVelocity;

// Optional Air Velocity Correction for Met > 1
    if (Conditions.AirVelocityCorrection && Conditions.Met>1)
     AirVelocity += 0.3f*(Conditions.Met-1);
    AirVelocity =  MAX(AirVelocity, 0.1f);

     PressureInPascals =  CalcVaporPressure() * 1000;

     ICL = .155f * Conditions.Clo;
     M = Conditions.Met * METFACTOR;
     W = Conditions.ExternalWork * METFACTOR;
     Tolerance = .00015f;
     MW = M - W;

// --- Compute the corresponding FCL value------------------------
     if (ICL < .078)
          FCL = 1.0f + 1.29f * ICL;
     else
          FCL = 1.05f + .645f * ICL;
     FCIC = ICL * FCL;
     P2 = FCIC*3.96f;
     P3 = FCIC*100.f;
     TRA = Conditions.MRT+273.f;
     TAA= Conditions.AirTemperature + 273.f;
     P1 = FCIC * TAA;
     P4 = 308.7f - .028f * MW + P2 * POWSP((TRA/100.f),4);

// --- First guess for surface temperature-------------------------
--
     TCLA = TAA + (35.5f-Conditions.AirTemperature) /
(3.5f*(6.45f*ICL+.1f));
     XN = TCLA / 100.f;
```

```
     XF = XN;
     HCF=12.1f*SQRTSP(AirVelocity);
     nIterations=0;

// ---COMPUTE SUFACE TEMPERATURE OF CLOTHING BY ITERATIONS---------
----
     while (nIterations < 150)
     {
          XF=(XF+XN)/2.f;
          HCN=2.38f*POWSP(ABSSP(100*XF-TAA),.25f);
          if (HCF>HCN)
               HC=HCF;
          else
               HC=HCN;
          XN=(P4+P1*HC-P2*POWSP(XF,4))/(100.f+P3*HC);
          nIterations++;
          if (nIterations>1 && ABSSP(XN-XF)<=Tolerance) break;
          TCL = 100.f*XN - 273.f;
     }

// --- COMPUTE PMV------------------------------------------
     if (nIterations < 150) // don//t do it if we didn//t find
clothing temperature
     {
          PM1=3.96f*FCL*(POWSP(XN,4)-POWSP((TRA/100.f),4));
          PM2 = FCL * HC * (TCL-Conditions.AirTemperature);
          PM3 = .303f * EXPSP(-.036f*M) + .028f;
          if (MW > OneMet)
               PM4 = .42f * (MW-OneMet);
          else
               PM4 = 0.f;
          PM5 = 3.05f*.001f*(5733.f-6.99f*MW-PressureInPascals);
          PM6 = 1.7f * .00001f * M * (5867.f-PressureInPascals) +
.0014f * M * (34.f-Conditions.AirTemperature);
          Results.PMV = PM3 * (MW-PM5-PM4-PM6-PM1-PM2);
          TCLN = (int)(TCL*100.f)/100.f;
     //---Compute PPD-----------------------------------------------
--------
          Results.PPD = 0.01f*(100.f - 95.f*EXPSP(-
.03353f*POWSP(Results.PMV,4)-.2179f*POWSP(Results.PMV,2)));
     }
     else
          return -1;
     return 0;
}
```

Appendix E Thermal Environment Survey: This appendix is informative

# THERMAL ENVIRONMENT SURVEY

Survey Number:

WHITE SECTIONS TO BE FILLED IN BY OCCUPANT

Surveyor's Name:

**1. Occupant's Name:**

**2. Date:**

**3. Time:**

**4. Approx. Outside Air Temperature:**

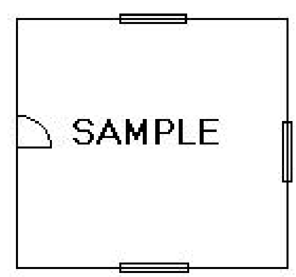
**°F**

**5. Sky:** (If applicable)
☐ Clear ☐ Mixed (Sun & Clouds)
☐ Overcast

**6. Seasonal Conditions**
☐ Winter ☐ Spring ☐ Summer ☐ Fall

**7. Occupants Clothing**
Please refer to the attached Table 1. Place a check mark next to the articles of clothing that you are currently wearing as you fill out this sheet. If you are wearing articles of clothing not listed in the table, please enter them into the space provided below.
Article:
Article:

**11. Occupant Location in Area**
**(**Place an "X" in the approximate place where you most often work.)




SURVEYOR'S USE ONLY

Clothing Insulation Summary:

Total $I_{cl}$ = ____________ clo

<table>
<tr><td colspan="2">8. Occupant Activity Level (Check the one that is most appropriate)<br>1. ☐ Reclining<br>2. ☐ Seated Quite<br>3. ☐ Office, school<br>4. ☐ Standing Relaxed<br>5. ☐ Light Activity Standing<br>6. ☐ Medium Activity, Standing<br>7. ☐ High Activity</td><td>Metabolic Rates (met)<br>1. 0.8 met<br>2. 1.0 met<br>3. 1.2 met<br>4. 1.2 met<br>5. 1.6 met<br>6. 2.0 met<br>7. 3.0 met</td></tr>
<tr><td colspan="2">9. Equipment (Equipment adding or taking away from the heat load.)</td><td rowspan="2">Total Heat Added/ Subtracted</td></tr>
<tr><td>Item (computers, copiers, fans, etc.)</td><td>Quantity</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="2">10. General Thermal Comfort (Check the one that is most appropriate)<br>1. ☐ Hot<br>2. ☐ Warm<br>3. ☐ Slightly Warm<br>4. ☐ Neutral<br>5. ☐ Slightly Cool<br>6. ☐ Cool<br>7. ☐ Cold</td><td>PMV-PPD Method – Sensation Scale<br>1. + 3<br>2. + 2<br>3. + 1<br>4. 0<br>5. – 1<br>6. – 2<br>7. – 3</td></tr>
<tr><td colspan="2">General Environment Comments:</td><td>Area Summary:</td></tr>
<tr><td colspan="2"></td><td rowspan="2">Room/Building Type:</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td>Outside Relative Humidity: %</td></tr>
<tr><td colspan="2"></td><td>Thermostat Setting:<br>°F</td></tr>
<tr><td colspan="2"></td><td>Humidity set-point:<br>%</td></tr>
<tr><td colspan="2"></td><td>Total Number of Occupants:</td></tr>
</table>

## Appendix F: References and Bibliography

Berglund, L.G., "Thermal Acceptability," ASHRAE Transactions 85: 825-834, 1979

Berglund, L.G. and R.R. Gonzalez, "Application of Acceptable Temperature Drifts to
Built Environments as a Mode of Energy Conservation," ASHRAE Transactions 84: 110-121, 1978

Berglund, L.G. and R.R. Gonzalez, "Occupant Acceptability of Eight Hour Long Temperature Ramps in the Summer at Low and High Humidities," ASHRAE Transactions 84: 278-284, 1978

Berglund, L.G. and A.P. Gagge, "Thermal Comfort and Radiant Heat," Proceedings of the 3rd National Passive Solar Conference of The American Section of The International Solar Energy Society, Inc. 1979

Berglund, L.G. and A.P.R. Fobelets, "Subjective Human Response to Low-Level Air Current and Asymmetric Radiation," ASHRAE Transactions, 93: 497-523, 1987

Bligh, J. and K.G. Johnson, "Glossary of Terms for Thermal Physiology," J. Appl. Physiol. 35: 941-961, 1973

Breunis, K. and J.P. deGroot, "Relative Humidity of the Air and Ocular Discomfort in a Group of Susceptible Office Workers," Proceedings of the Fourth International Conference on Indoor Air Quality and Climate, 2: 625-629, 1987

de Dear R.J.and G.Schiller Brager (1998) “Developing an adaptive model of thermal comfort and preference,” ASHRAE Transactions., V.104(1a), pp.145-167

Fanger, P.O. Thermal Comfort. Robert E. Krieger, Malabar, FL. 1982

Fanger, P.O., B.M. Ipsen, G. Langkilde, B.W. Olesen, N.K. Christensen and S. Tanabe, "Comfort Limits for Asymmetric Thermal Radiation," Energy and Buildings, 8:225-236, 1985

Fanger, P.O., B.W. Olesen, G. Langkilde and L. Banhidi "Comfort Limits for Heated Ceilings," ASHRAE Transactions 86: 141-156, 1980

Fanger, P.O., A. K. Melikov, H. Hanzawa and J. Ring, "Air Turbulence and Sensation of Draught," Energy and Buildings, 12: 21-39, 1988

Fanger, P.O. and N.K. Christensen, "Perception of Draught in Ventilated Spaces," Ergonomics, 29: 215-235, 1986

Fishman, D.S. and S.L. Pimbert, "Survey of Subjective Responses to the Thermal Environment in Offices," Indoor Climate, P.O. Fanger and O. Valbjorn
(eds.), Danish Building Research Institute, Copenhagen, 1979

Fobelets, A.P.R. and A.P. Gagge. "Temperature ET, As a Measure of the Enthalpy of the Human Indoor Environment," ASHRAE Transactions 94: 12-31, 1988

Gagge, A.P. and R.G. Nevins, "Effect of Energy Conservation Guidelines on Comfort, Acceptability and Health," Final Report of Contract #CO-04-51891-00, Federal Energy Administration, 1976

Gagge, A.P., Y. Nishi and R.G.Nevins, "The Role of Clothing in Meeting FEA Energy Conservation Guidelines," ASHRAE Transactions 82: 234-247, 1976

Gagge, A.P., Y. Nishi and R.G. Nevins, "Role of Clothing in Meeting FEA Energy Conservation Guidelines," ASHRAE Transactions 82: 234-247, 1976

Griffiths, I.D. and D.A. McIntyre, "Sensitivity to Temporal Variations in Thermal Conditions," Ergonomics, 17: 499-507, 1974

Goldman, R.F., "The Role of Clothing in Achieving Acceptability of Environmental Temperatures Between 65 °F and 85 °F (18 °C and 30 °C)," Energy Conservation Strategies in Buildings, J.A.J. Stolwijk, (Ed.) Yale University Press, New Haven, 1978

Hanzawa, H., A.K. Melikov and P.O. Fanger, "Airflow Characteristics in the Occupied Zone of Ventilated Spaces," ASHRAE Transactions, 93: 524-539, 1987

Jones, B.W., K. Hsieh and M. Hashinaga, "The Effect of Air Velocity on Thermal Comfort at Moderate Activity Levels," ASHRAE Transactions 92, Part 2B: 761-769, 1986

Laviana, J.E., F.H. Rohles and P.E. Bullock, "Humidity, Comfort and Contact Lenses," ASHRAE Transactions 94: 3-11, 1988

Lammers, J.T.H., L.G. Berglund and J.A.J. Stolwijk, "Energy Conservation and Thermal Comfort in a New York City High Rise Office Building," Environmental Management 2: 113-117, 1978

McCullough, E.A. and D.P. Wyon, "Insulation Characteristics of Winter
and Summer Indoor Clothing," ASHRAE Transactions 89: 614-633, 1983

McCullough, E.A., B.W. Jones and J. Huck, "A Comprehensive Data Base for Estimating Clothing Insulation," ASHRAE Transactions 92: 29-47, 1985

McIntyre, D.A., "Overhead Radiation and Comfort," The Building Services Engineer 44: 226-232, 1976

McIntyre, D.A., "Preferred Air Speeds for Comfort in Warm Conditions," ASHRAE Transactions 84: 264-277, 1978

McNall, P.E., Jr. and R.E. Biddison, "Thermal and Comfort Sensations of Sedentary Persons Exposed to Asymmetric Radiant Fields," ASHRAE Transactions 76: 123-136, 1970

McNall, P.E., Jr., J. Jaax, F.H. Rohles, R.G. Nevins and W. Springer,"Thermal Comfort (Thermally Neutral) Conditions for Three Levels of Activity," ASHRAE Transactions 73 (Part I): I.3.1-I.3.14, 1967

Melikov, A.K., H. Hanzawa and P.O. Fanger, "Airflow Characteristics in the Occupied Zone of Heated Spaces Without Mechanical Ventilation," ASHRAE Transactions, 94: 52-70, 1988

Nevins, R.G. and A.M. Feyerherm, "Effect of Floor Surface Temperature on Comfort. Part IV: Cold Floors," ASHRAE Transactions 73 (Part II): III.2.1 - III.2.8, 1967

Nevins, R.G., K.B. Michaels and A.M. Feyerherm, "The Effect of Floor Surface Temperature on Comfort. Part II: College Age Females," ASHRAE Transactions 70: 37-43, 1964

Nevins, R.G. and P.E. McNall, Jr. "ASHRAE Thermal Comfort Standards as Performance Criteria for Buildings," CIB Commission W 45 Symposium, Thermal Comfort and Moderate Heat Stress, Watford, U.K. 1972 (Published by HMSO London 1973)

Nielsen, B., I. Oddershede, A. Torp and P.O. Fanger, "Thermal Comfort During Continuous and Intermittent Work," Indoor Climate,

P.O. Fanger and O. Valbjorn, eds., Danish Building Research Institute, Copenhagen, 1979, pp. 477-490

Nilsson, S.E. and L. Andersson, "Contact Lens Wear in Dry Environments," ACTA Ophthalmologica 64: 221-225, 1986

Nishi, Y. and A.P. Gagge, "Effective Temperature Scale Useful for Hypo- and Hyperbaric Environments," Aviation, Space and Environmental Medicine 48: 97-107, 1977

Olesen, B.W. "A New and Simpler Method for Estimating the Thermal Insulation of a Clothing Ensemble," ASHRAE Transactions 92: 478-492, 1985

Olesen, B.W., "Thermal Comfort Requirements for Floors," Proceedings of The Meeting of Commissions B1, B2, E1 of IIR, Belgrade, 1977, pp 307-313

Olesen, B.W., "Thermal Comfort Requirements for Floors Occupied by People with Bare Feet," ASHRAE Transactions 83: 41-57, 1977

Olesen, S., P.O. Fanger, P.B. Jensen and O.J. Nielsen, "Comfort Limits for Man Exposed to Asymmetric Thermal Radiation," CIB Commission W 45 Symposium, Thermal Comfort and Moderate Heat Stress, Watford, U.K. 1972 (Published by HMSO London 1973)

Olesen, B.W., E. Mortensen, J. Thorshauge and B. Berg-Munch, "Thermal Comfort in a Room Heated by Different Methods," ASHRAE Transactions 86: 34-48, 1980

Olesen, B.W., M. Scholer and P.O. Fanger, "Discomfort Caused by Vertical Air Temperature Differences," Indoor Climate, P.O. Fanger and O. Valbjorn, eds., Danish Building Research Institute, Copenhagen, 1979

Rohles, F.H., J.E. Woods and R.G. Nevins, "The Effect of Air Speed and Temperature on the Thermal Sensations of Sedentary Man," ASHRAE Transactions 80: 101-119, 1974

Rohles, F.H., S.A. Konz and B.W. Jones, "Ceiling Fans as Extenders of the Summer Comfort Envelope," ASHRAE Transactions 89: 245-263, 1983

Rohles, F.H., G.A. Milliken, D.E. Skipton, and I. Krstic, "Thermal Comfort During Cyclical Temperature Fluctuations," ASHRAE Transactions 86: 125-140, 1980

Rohles, F.H., Jr., J.E. Woods and R.G.Nevins, "The Influence of Clothing and Temperature on Sedentary Comfort," ASHRAE Transactions 79: 71-80, 1973

Scheatzle, D.G., H. Wu. and J. Yellott, "Extending The Summer Comfort Envelope with Ceiling Fans in Hot, Arid Climates," ASHRAE Transactions 95, Part 1: 269-280, 1989

Sprague, C.H. and P.E. McNall, Jr., "Effects of Fluctuating Temperature and Relative Humidity on the Thermal Sensation (Thermal Comfort) of Sedentary Subjects," ASHRAE Transactions 77: 183-199, 1971

Wyon, D.P., Th. Asgeirsdottir, P. Kjerulf-Jensen and P.O. Fanger, "The Effects of Ambient Temperature Swings on Comfort, Performance and Behavior," Arch. Sci. Physiol. 27: 441-458, 1973